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(54) **VARIABLE FOCAL LENGTH LENSES**

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Related U.S. Application Data

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(51) **Int. Cl.**[7] **G02B 26/00**
(52) **U.S. Cl.** **235/462.35**; 235/383
(58) **Field of Search** 235/383, 462.35; 349/200, 84, 177; 359/319

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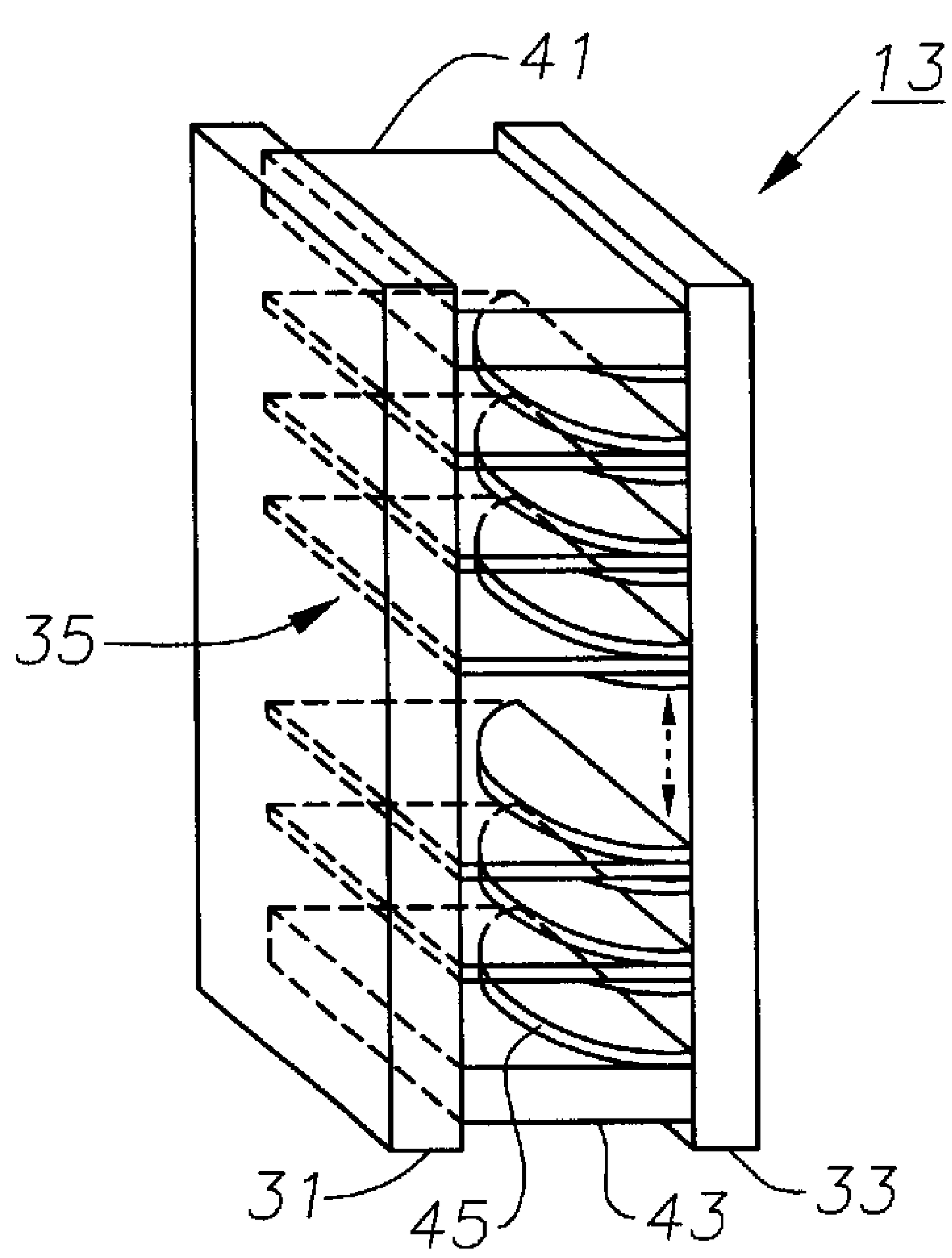
(57) **ABSTRACT**

A bar code reader for an automated storage library has a lens assembly with a pair of polarized liquid crystal lenses. Each lens has pair of parallel glass plates that are separated by upper and lower glass substrates. A series of polymer films are symmetrically spaced apart between the substrates. Both the substrates and the films are perpendicular to the glass plates. Electrodes are formed on the films and combine to form a semi-cylindrical stack of film. Liquid crystal fills the spaces between adjacent pairs of the films. The films are coated and/or treated by an alignment process to predispose the liquid crystals to a specific rotational direction. When a selected voltage is applied between adjacent ones of the electrodes, the liquid crystals are synchronously rotated to alter their refractive index to a desired value. Thus, when the layers of each lens are manipulated in unison, the bar code reader is able to quickly adjust its focal length to read bar codes at various distances.

20 Claims, 6 Drawing Sheets



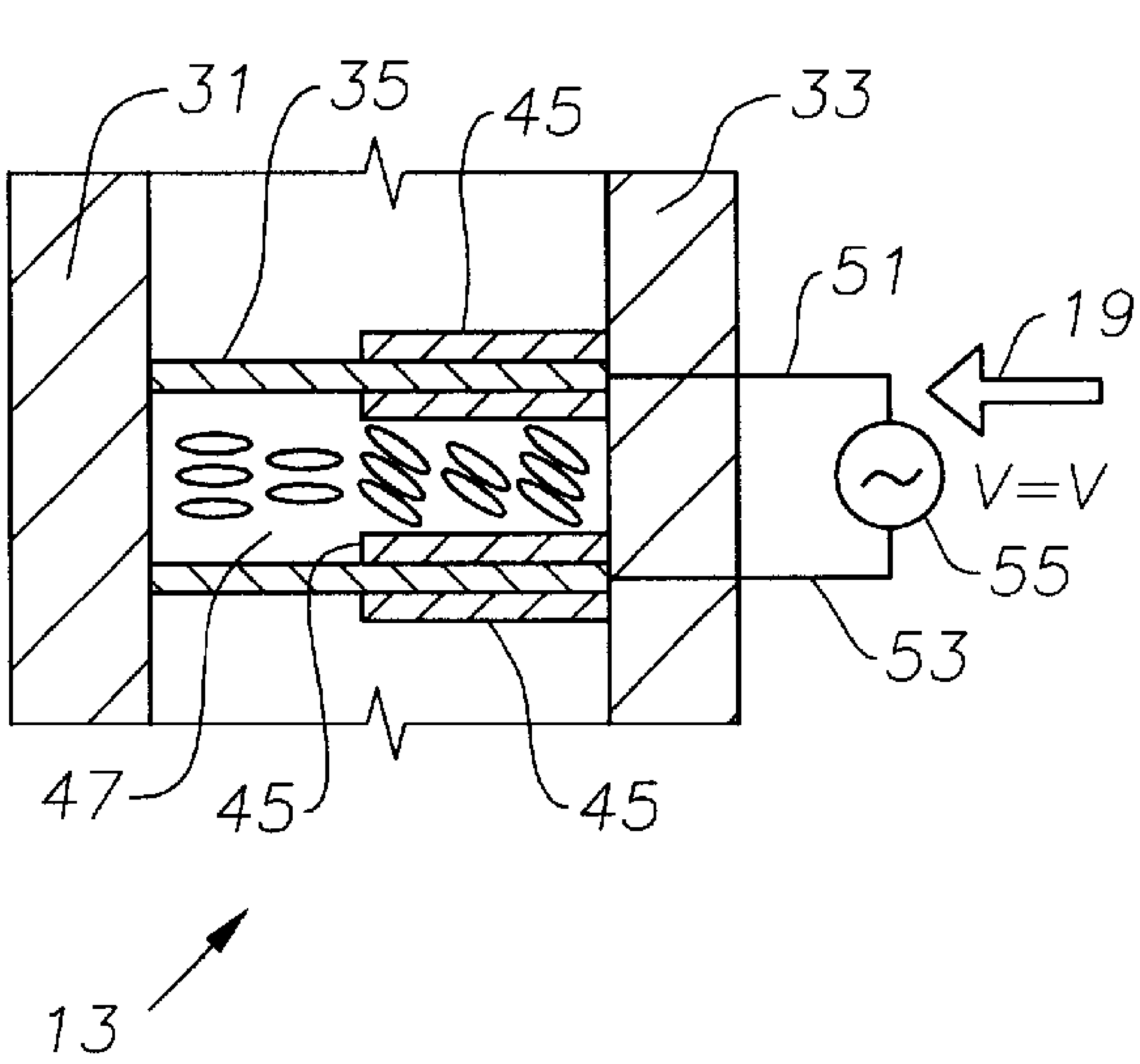


Fig. 1

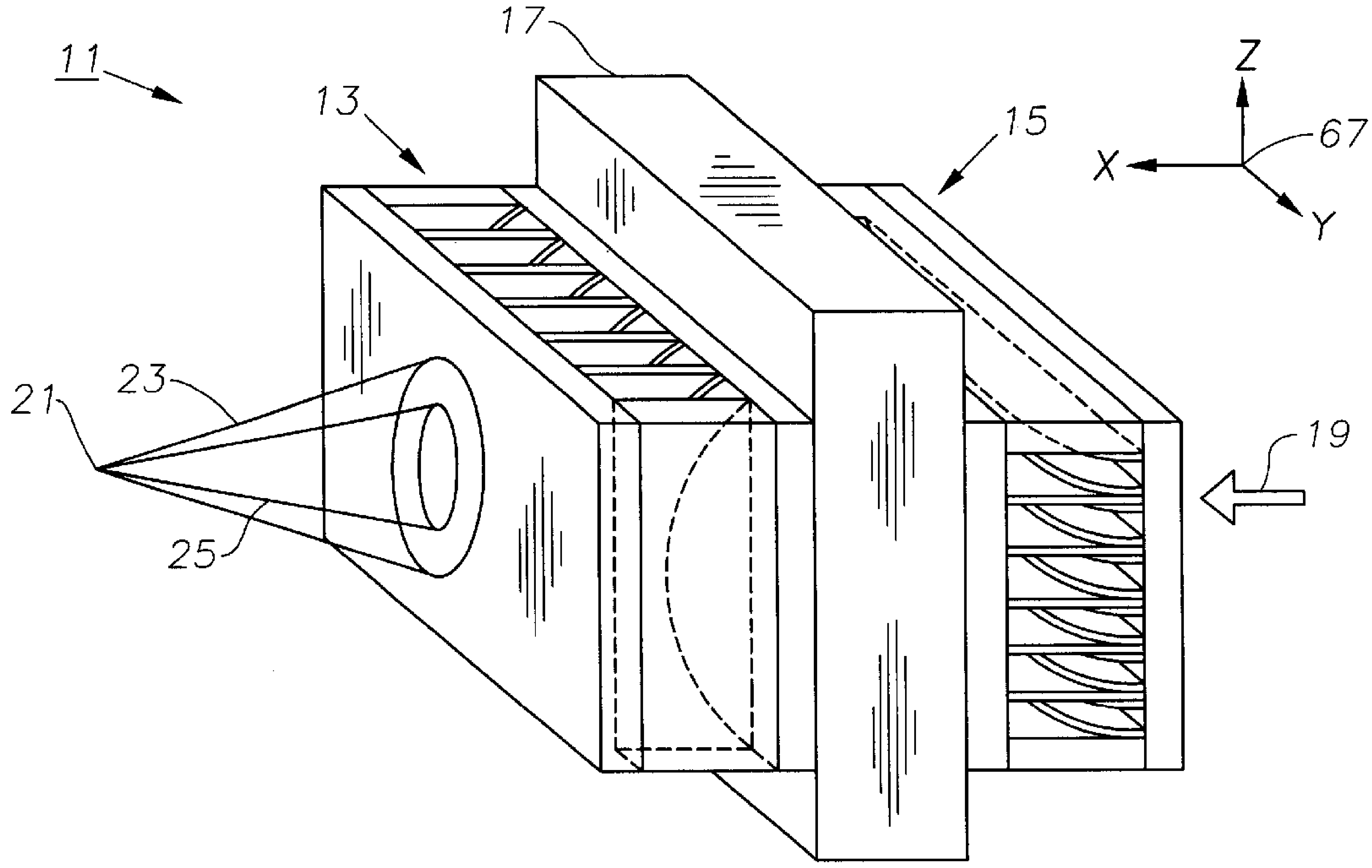


Fig. 2

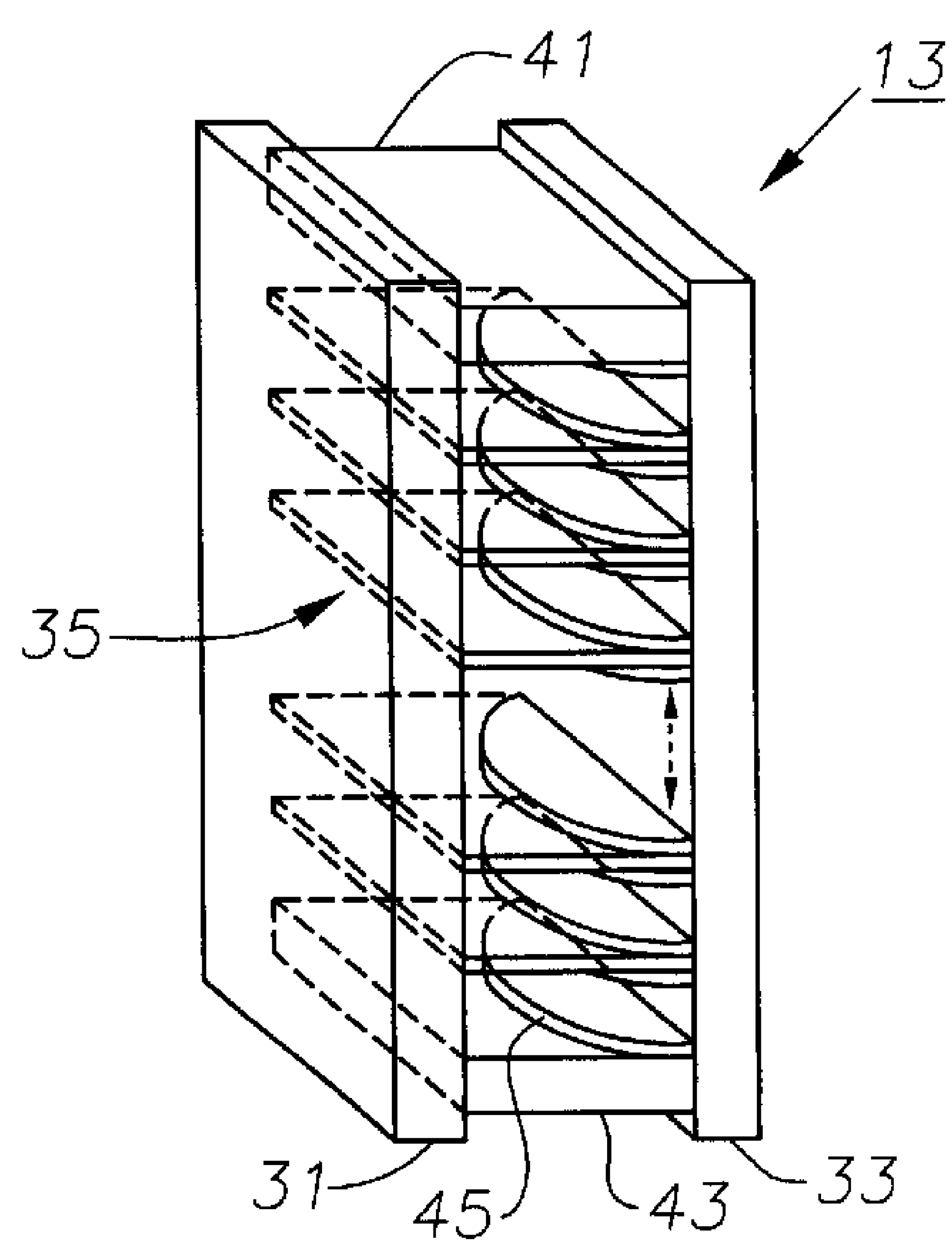


Fig. 3

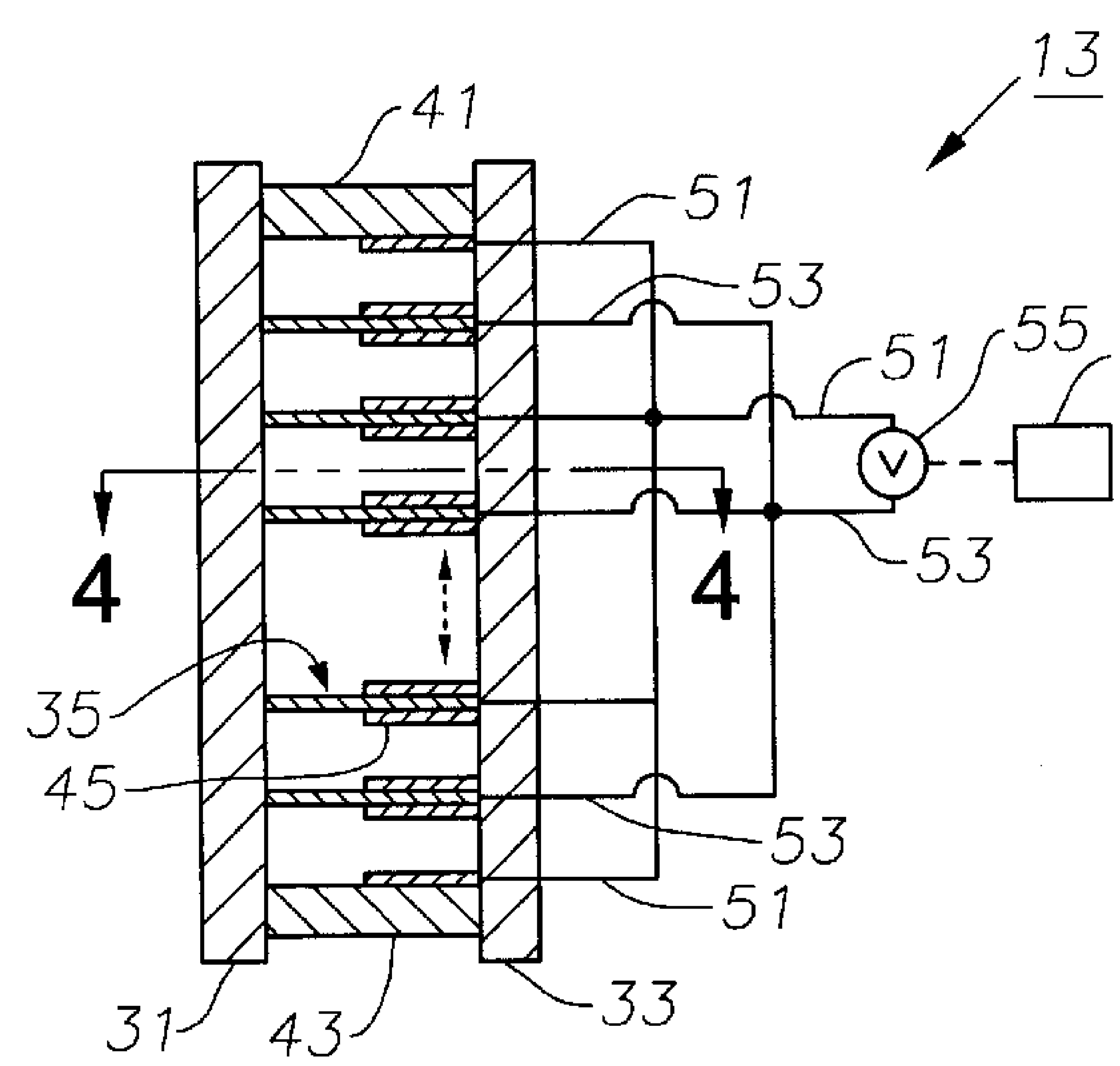


Fig. 4

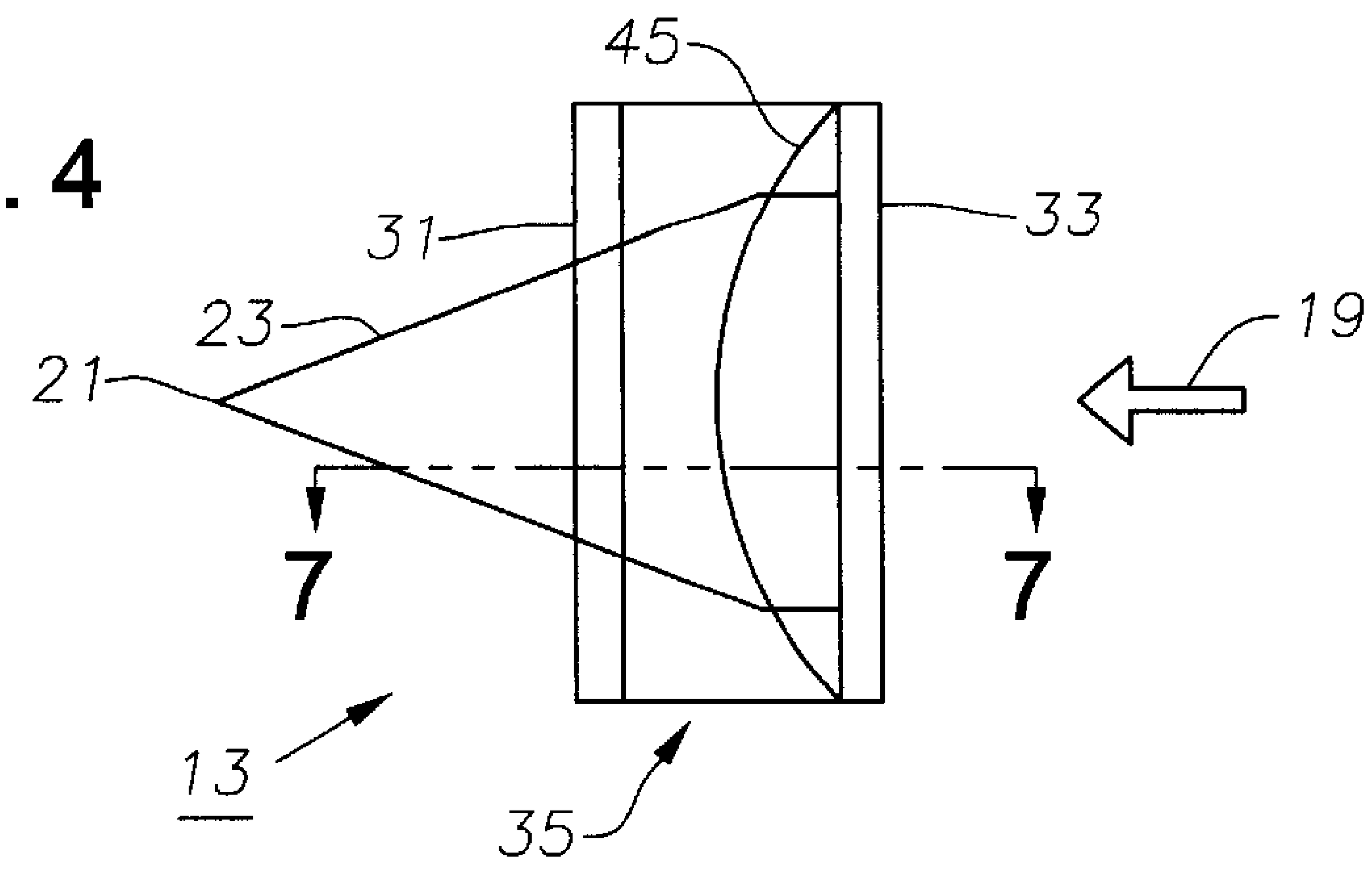


Fig. 5

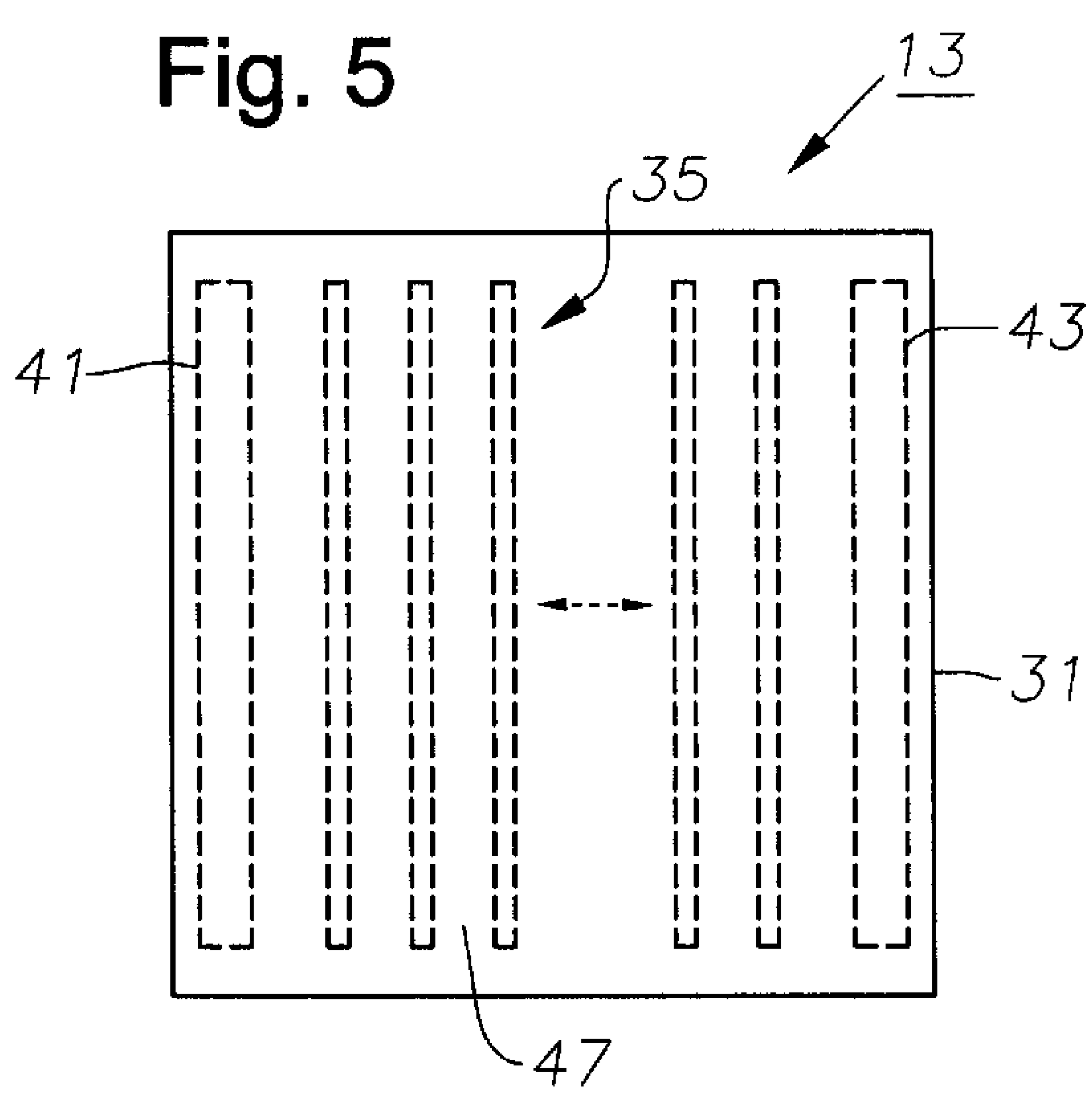


Fig. 6

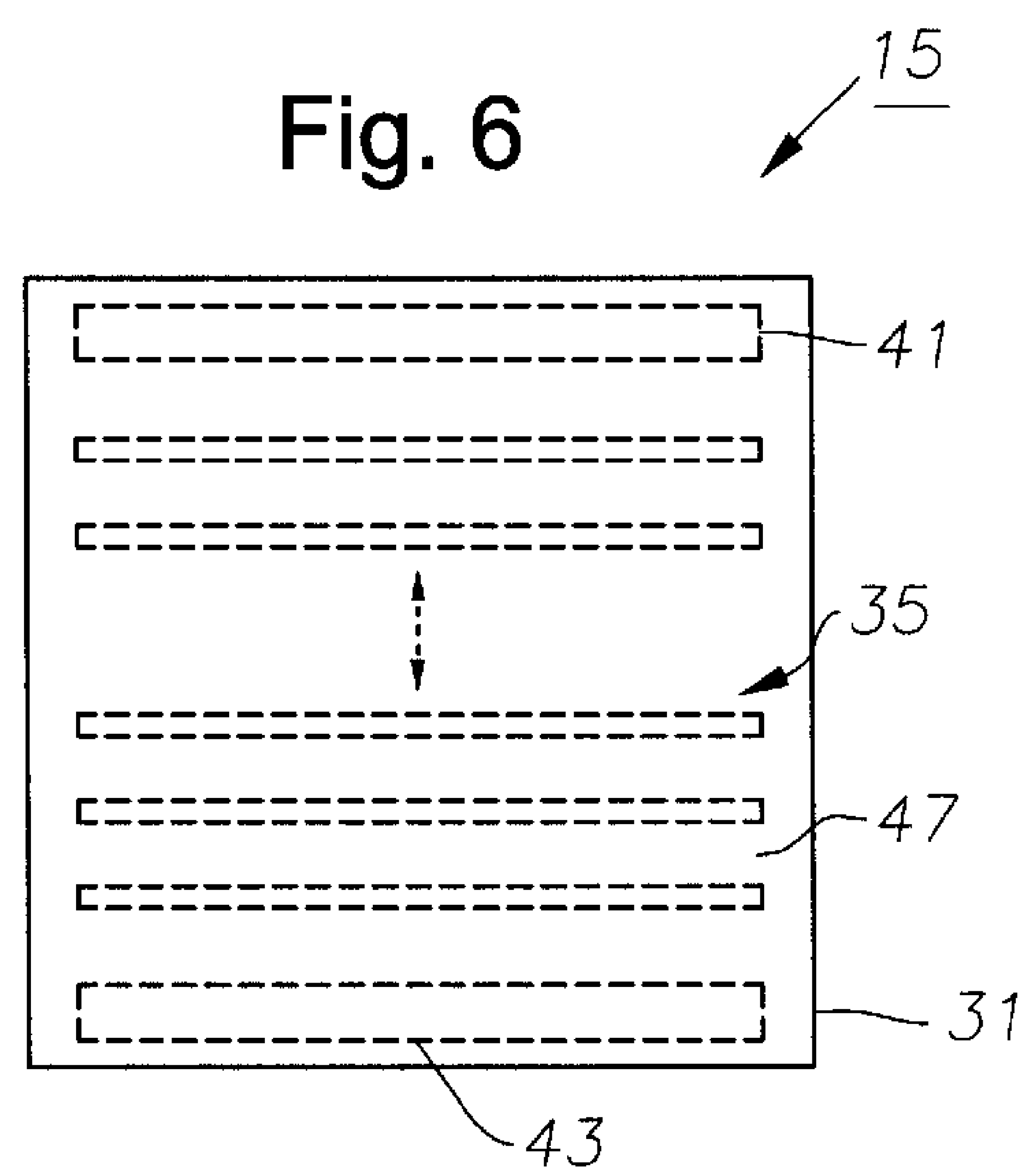


Fig. 7

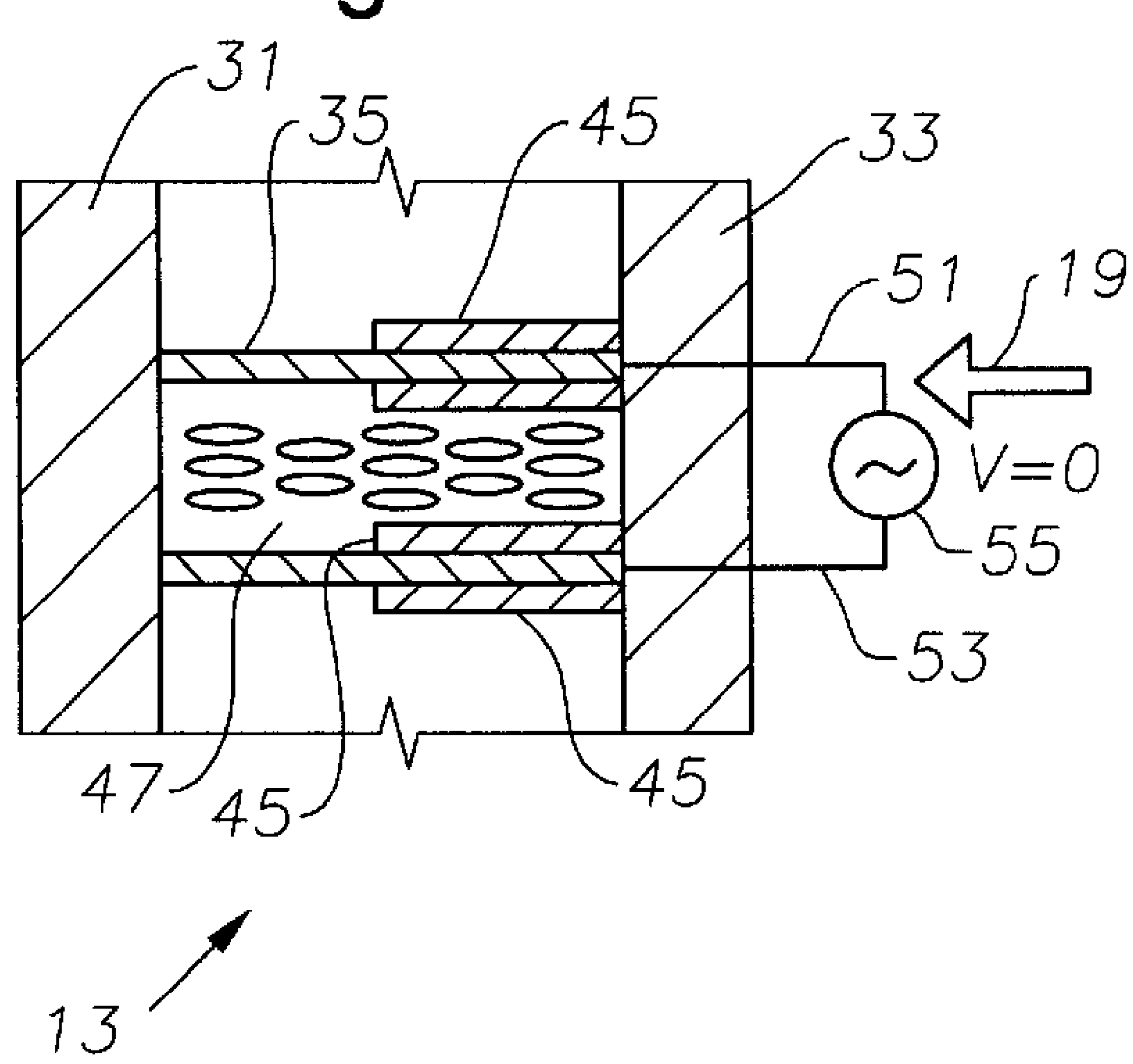


Fig. 8

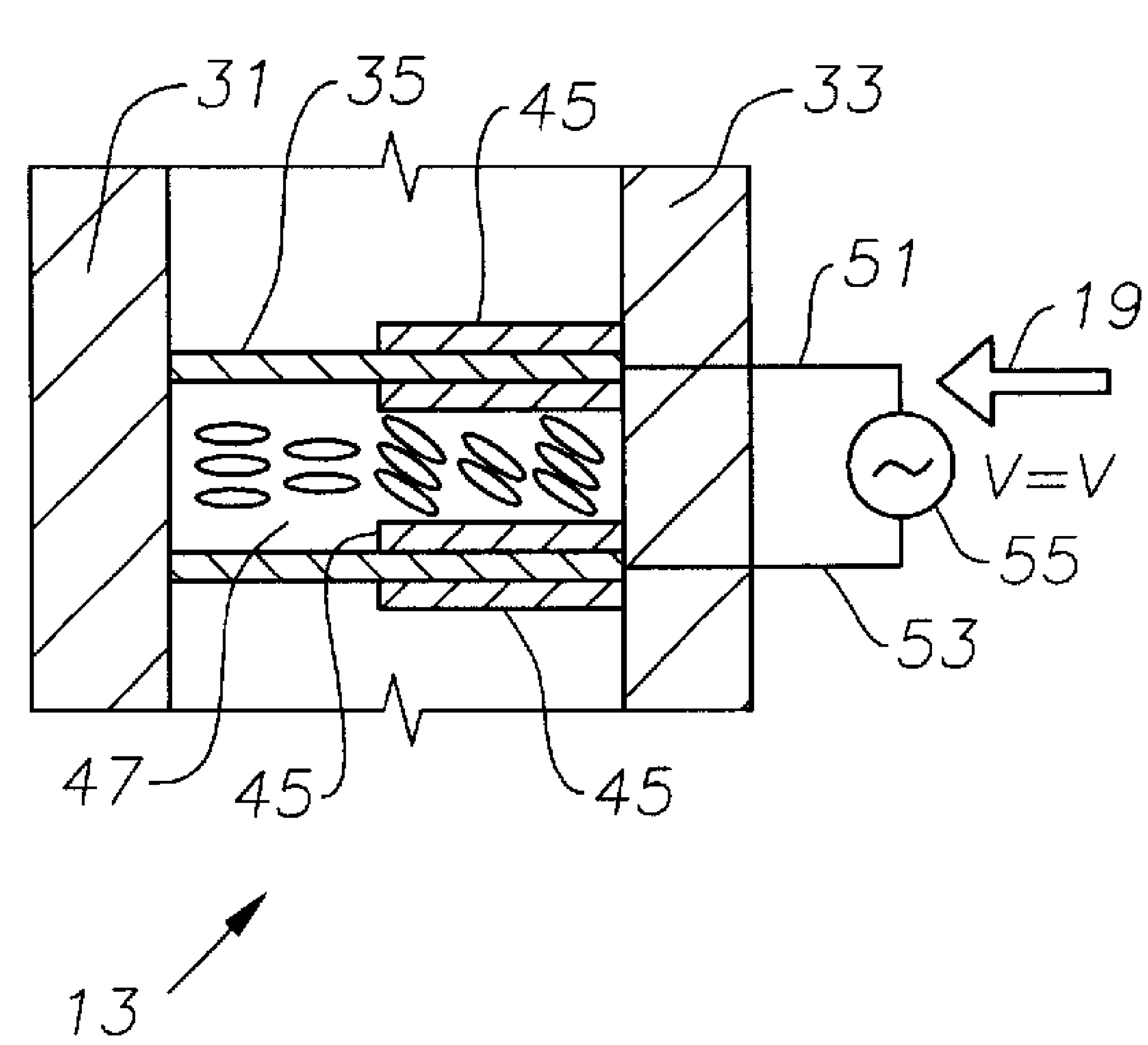


Fig. 10

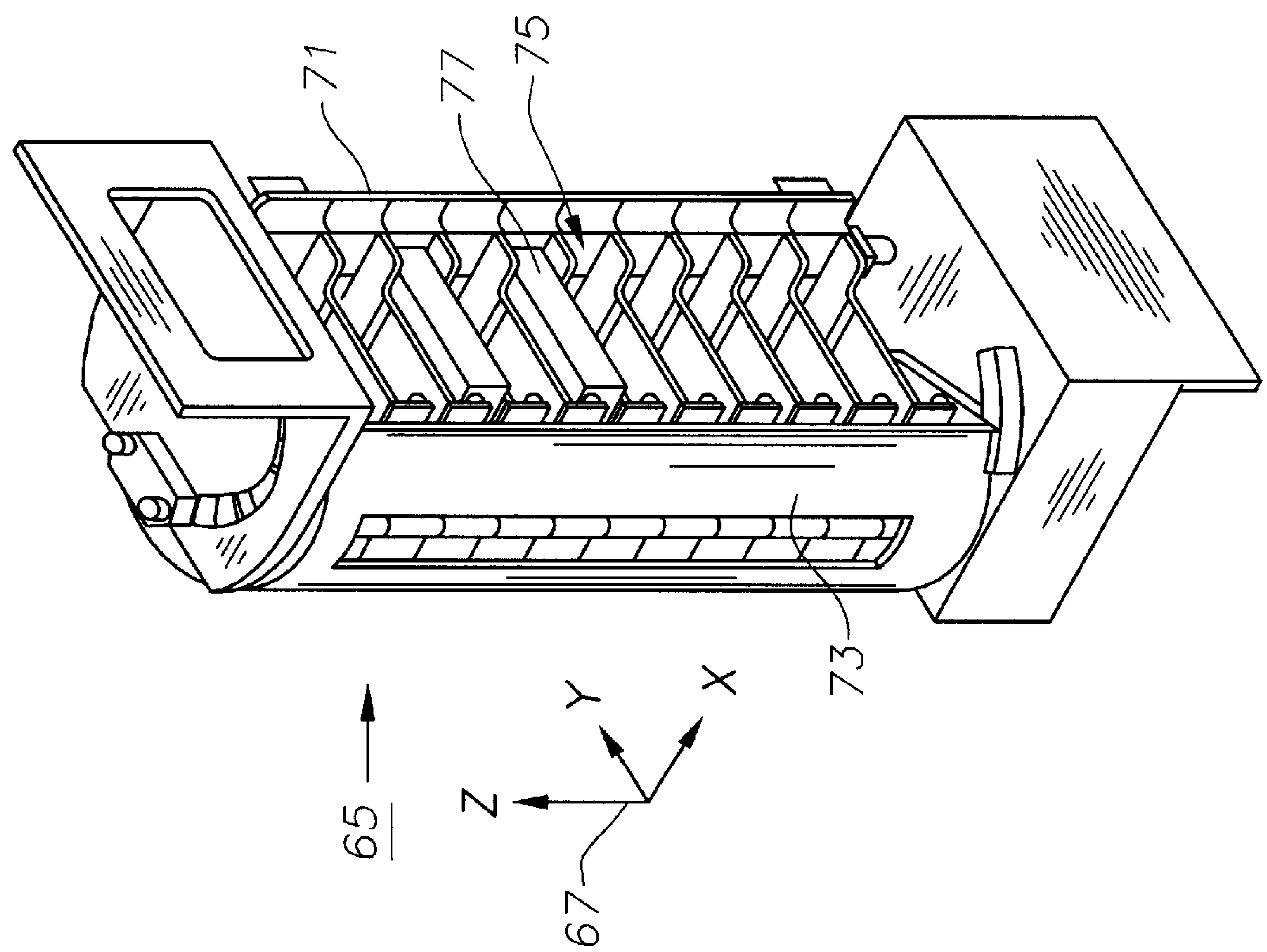
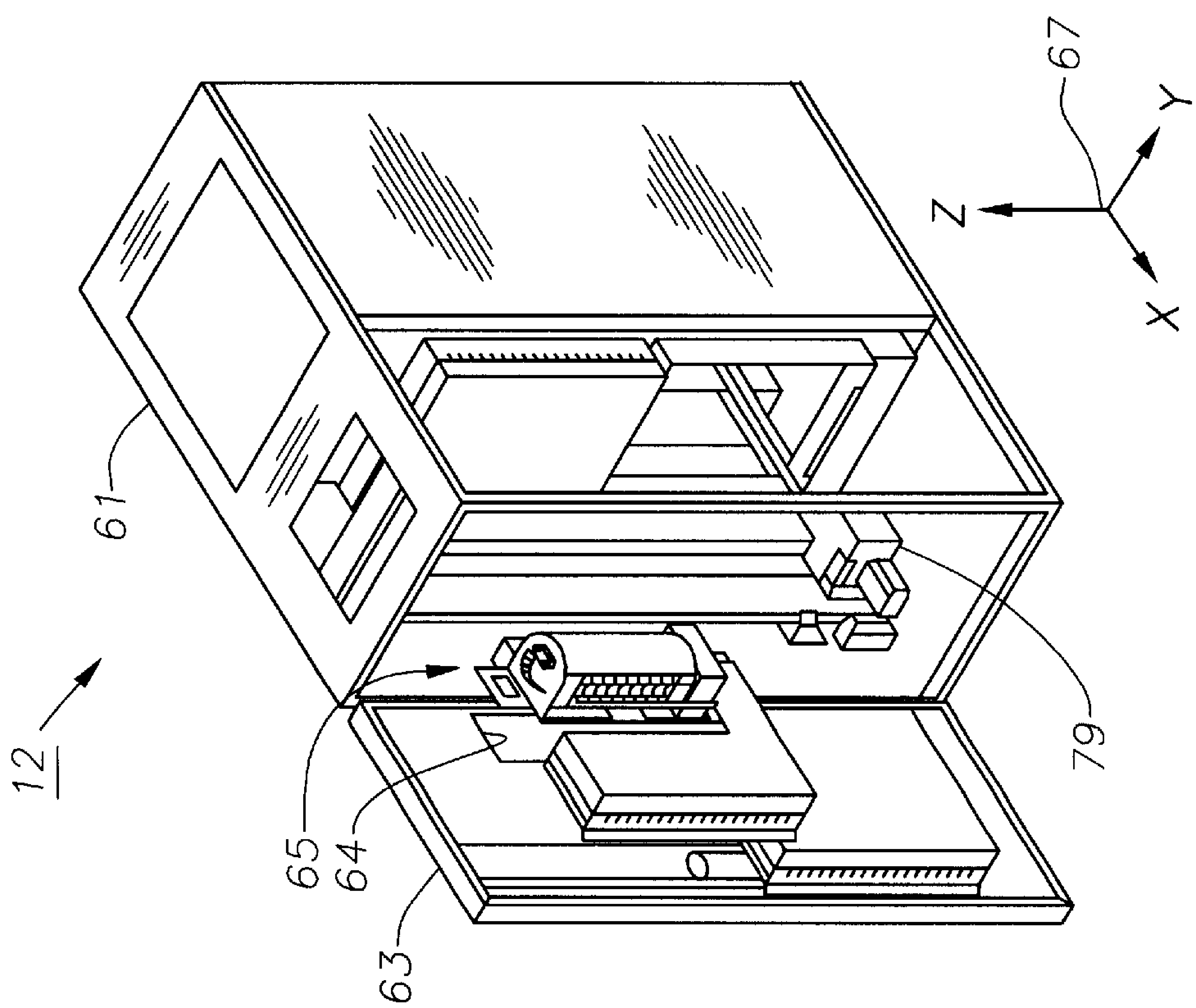


Fig. 9



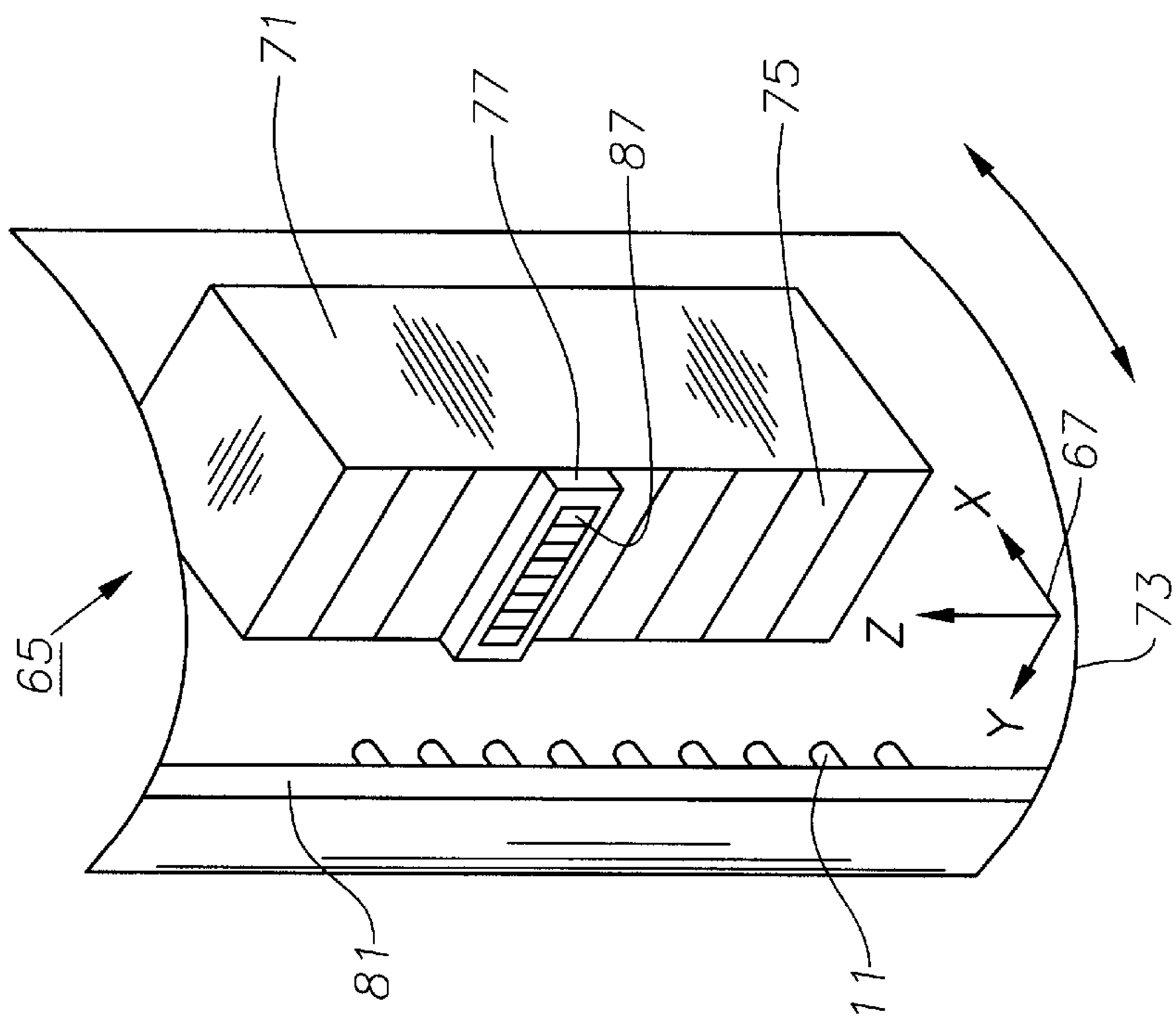


Fig. 12

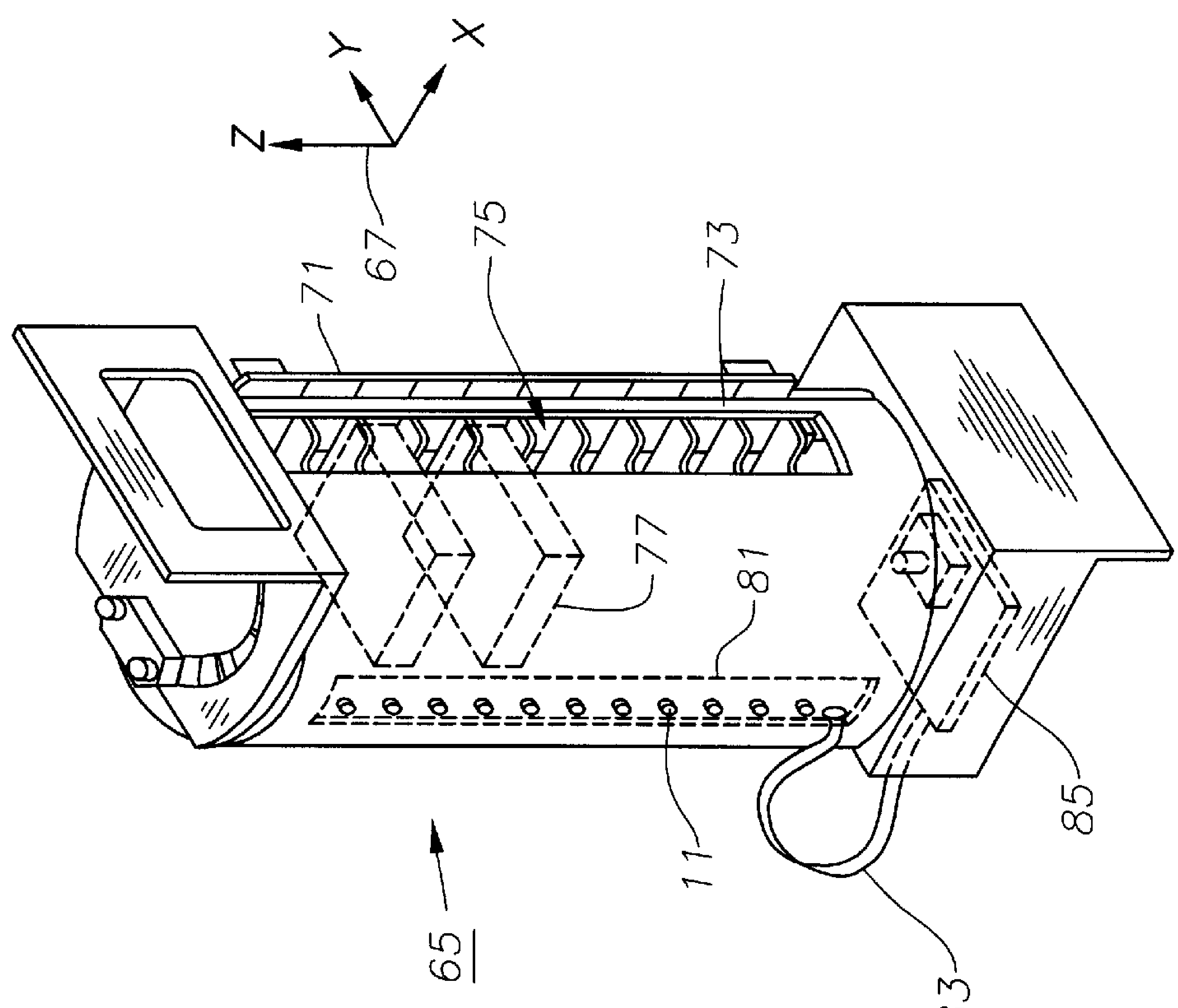


Fig. 11

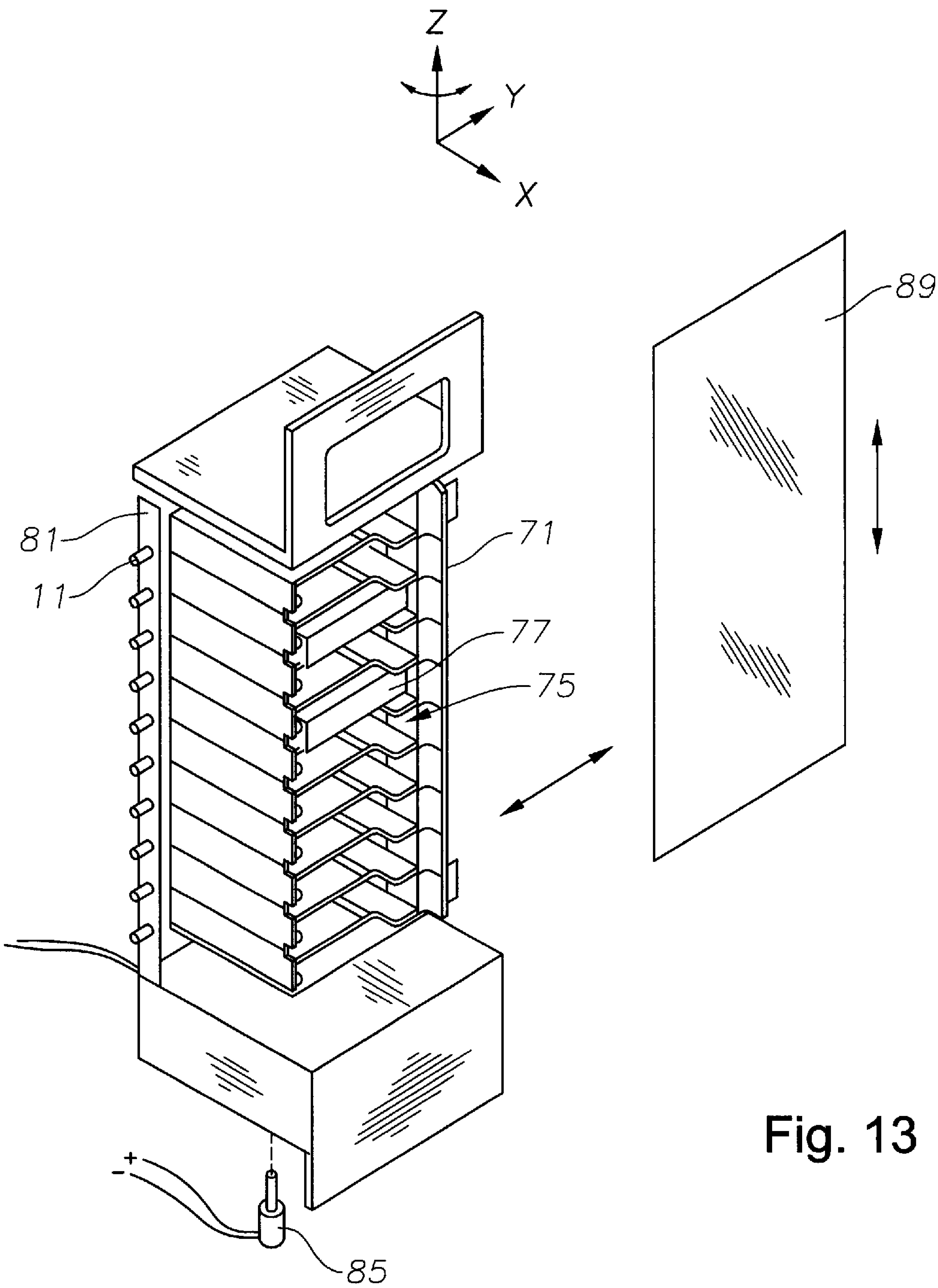


Fig. 13

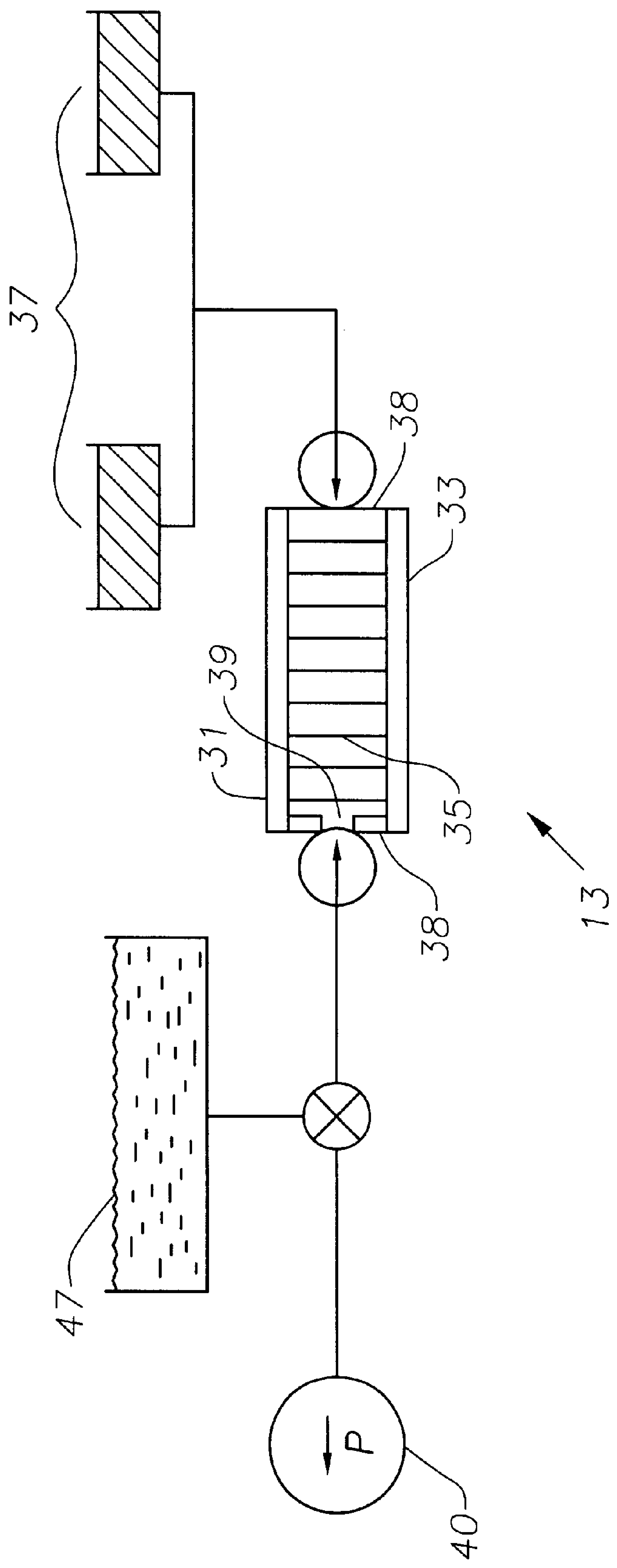


Fig. 14

VARIABLE FOCAL LENGTH LENSES

This is a Division of application Ser. No. 09/333,079, filed Jun. 14, 1999, now U.S. Pat. No. 6,250,550.

BACKGROUND OF THE INVENTION

1. Technical Field

This invention relates in general to automated media storage libraries and in particular to an automated media storage library with a variable focal length lens for scanning bar coded labels associated with data storage media in the library.

2. Background Art

Automated media storage libraries which utilize storage devices such as data cartridges are well known in the art. A large number of the cartridges are typically mounted in a rotatable housing or magazine and individually indexed with bar coded labels. The labels may be positioned in a variety of locations, including on the cartridges themselves, adjacent to a mail slot on the housing, or on a door around each mail slot. A bar code reader system is located adjacent to the housing for reading the labels so that the desired cartridge may be selected and accessed. In order to scan a label associated with a moving cartridge and/or reader system, the focal length of the reader must be adjustable to accommodate for cartridges and labels which differ in size and, thus, distance from the reader. This problem has become even more acute with libraries which contain multimedia storage devices.

Therefore, it is a feature of the present invention to provide an assembly with a high speed, variable focal length lens for reading bar code labels on media devices located in an automated media storage library.

SUMMARY OF THE INVENTION

A bar code reader for an automated storage library has a lens assembly with a pair of polarized liquid crystal lenses. Each lens has pair of parallel glass plates that are separated by upper and lower glass substrates. A series of rectangular polymer films are symmetrically spaced apart between the two glass substrates. Both the substrates and the films are perpendicular to the glass plates. A semi-circular electrode is formed on each side of each piece of film to form a semi-cylindrical "stack" of film. The electrodes do not completely cover the film. Liquid crystal fills the space between each adjacent pair of the films. The films are coated and/or treated by an alignment process to predispose the liquid crystals to an alignment and rotation direction.

When a selected voltage is applied between adjacent ones of the electrodes, the liquid crystals are synchronously rotated to alter their refractive index to a desired value. Thus, when the layers of each lens are manipulated in unison, the bar code reader is able to quickly adjust its focal length to read bar codes labels on media devices at various distances. For example, when the applied voltage is zero, there is no refractive index difference between the electrode portion and the non-electrode portion of the liquid crystal. Therefore, the focal length is infinite. Applying a voltage to the electrodes alters the refractive index of the liquid crystal and, thus, shortens the focal length of the lens assembly to the proper distance for reading the labels.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the features, advantages and objects of the invention, as well as others which will become

apparent, are attained and can be understood in more detail, more particular description of the invention briefly summarized above may be had by reference to the embodiment thereof which is illustrated in the appended drawings, which drawings form a part of this specification. It is to be noted, however, that the drawings illustrate only a preferred embodiment of the invention and is therefore not to be considered limiting of its scope as the invention may admit to other equally effective embodiments.

FIG. **1** is an isometric view of a lens assembly constructed in accordance with the invention.

FIG. **2** is an isometric view of a single liquid crystal (LC) lens of the lens assembly of FIG. **1**.

FIG. **3** is a schematic, sectional side view of the LC lens of FIG. **2**.

FIG. **4** is a schematic top view of the LC lens of FIG. **2** taken along the line **4**—**4** of FIG. **3**.

FIG. **5** is a front view of the LC lens of FIG. **2** showing a first configuration.

FIG. **6** is a front view of the LC lens of FIG. **2** showing a second configuration.

FIG. **7** is a schematic, enlarged, sectional side view of a portion of the LC lens of FIG. **2** shown without an applied voltage and taken along the line **7**—**7** of FIG. **4**.

FIG. **8** is a sectional side view of the portion of the LC lens of FIG. **7** shown with an applied voltage.

FIG. **9** is an isometric view of an automated media storage library that incorporates the lens assembly of FIG. **1** and is constructed in accordance with the invention.

FIG. **10** is an enlarged front isometric view of a cartridge station of the library of FIG. **9** wherein the door of the station is open.

FIG. **11** is a schematic front isometric view of the cartridge station of FIG. **10** with the door closed.

FIG. **12** is a schematic, rear isometric view of the cartridge station of FIG. **11**.

FIG. **13** is a schematic, rear isometric view of an alternate embodiment of the cartridge station of FIG. **11**.

FIG. **14** is a schematic drawing of a method for making the LC lens of FIG. **2**.

BEST MODE FOR CARRYING OUT THE INVENTION

Referring to FIG. **1**, a sensor or lens assembly **11** for use with a bar code reader in an automated media storage library **12** (FIG. **9**) is shown. Lens assembly **11** comprises a front liquid crystal (LC) lens **13**, a rear LC lens **15**, and a transparent spacer plate **17** therebetween. A laser light source **19** (indicated schematically by the arrow) is projected into rear lens **15** from right to left. Light source **19** is independently focused by each lens **13**, **15** into a conical beam **23**, **25**, respectively, and focused to a common point **21** to the left of front lens **13**. The thickness of spacer plate **17** is selected to be one half of one wavelength of the light emitted by light source **19**.

Lenses **13**, **15** are identical in construction and are illustrated in detail in FIGS. **2**–**4**. For simplicity, only lens **13** will be discussed even though the following description applies equally to lens **1S**. Lens **13** consists of a pair of parallel, glass plates, **31**, **33**, and a plurality of thin, rectangular, insulative, polymer films **35** therebetween. In the embodiment shown, plates **31**, **33** are 1 mm squares. The inner surfaces of plates **31**, **33** are spaced apart by 70 microns which is also the width of films **35**. Each film **35** has a length of 1 mm and a thickness of 2 microns. A pair of glass substrates **41, 43** are located at the upper and lower ends, respectively, of lens **13** with films **35** therebetween. Films **35** and substrates **41, 43** are parallel to one another, and perpendicular to plates **31, 33**. Films **35** and substrates **41, 43** are evenly spaced apart from one another by 50 microns. Thus, in the embodiment shown, there are 19 films **35** which define 20 layers between substrates **41, 43**.

The upper and lower surfaces of each film **35** and the inner surfaces of substrates **41, 43** have an electrode **45** formed on them. In the embodiment shown, electrodes **45** are semi-circular in shape with a radius of 2 mm, but they may be formed in any other shape that also would produce a positive focal length. As will be discussed below, the radius of electrodes **45** is determined by the range of focal lengths required by the application. Although electrodes **45** have a thickness that is less than 10 nm, they are shown much thicker for illustration purposes. Electrodes **45** may be sputtered to the desired shape with a patterned mask, or sputtered over the entire rectangular surface of films **35** and substrates **41, 43**, and then chemically etched with a patterned photo-resist to obtain the desired shape. Other processes, such as photolithography, may also be used to obtain the desired pattern for electrodes **45**.

After electrodes **45** are formed, an alignment material (not shown) is spin-coated or printed on top of the electrodes and the remaining surface area of the underlying substrate. The most popular alignment material for liquid crystal is polyimide. However, any material for homogenous parallel alignment, such as polyvinyl alcohol, may be used. The alignment material has a thickness of 30 nm or less. After the alignment material has coated the electrodes and their substrates, an alignment process, such as rubbing, is performed on the alignment material to set the desired alignment direction for the liquid crystals. Other alignment processes, such as photoalignment, which establish parallel homogenous alignment may also be used.

The alignment effect from the surface of the substrate is limited to several dozen microns (approximately 30 to 70 microns). Therefore, films **35** are mounted in spacers (not shown) to maintain their 50 micron spacing. The spacing between films **35** could be larger or smaller, as long as the alignment effect is maintained. The films **35**, substrates **41, 43**, and plates **31, 33** are then assembled together to form lens **13** before the liquid crystals **47** are injected into the spaces or cells.

Note that the total thickness of each film **35**, including an electrode **45** and outer layer of alignment material on each surface (which are substantially negligible at 20 nm and 60 nm total) is approximately 2 microns. Since there is only one film **35** for every 50 microns of transmission width, the amount of light transmitted by lens assembly **11** is diminished by only 4% per lens **13, 15**, or 8% total.

Referring to FIG. **14**, lens **13** is assembled by dispensing heat curable epoxy resin **37** around the perpendicular glass plates **31, 33**, films **35**, substrates **41, 43** and spacers to form a seal **38** therebetween. An opening **39** in the lens body assembly **13** is reserved for injecting the liquid crystals **47**. After curing the epoxy, the liquid crystals **47** are injected through opening **39** into the cells between films **35** with a vacuum injection technique. The air in the cells is removed with a pump **40** to create a vacuum and opening **39** in seal **38** is immersed into the liquid crystals **47** to fill the cells by capillary action. Opening **39** is sealed after the lens **13** is filled.

As shown in FIGS. **5** and **6**, liquid crystal **47** fills the spaces between films **35** and substrates **41, 43**. FIGS. **1, 5** and **6** also show the perpendicular orientation of lenses **13, 15** relative to one another and the lens assembly **11** overall. In the embodiment shown, the layers of front lens **13** are vertically oriented, and the layers of rear lens **15** are horizontally oriented to form a polarized lens assembly **11**.

Each lens **13, 15** can only focus in one direction, hence, lenses **13, 15** are rotated and fixed at 90 degrees relative to each other. Spacer plate **17** is required for two-dimensional focusing. For example, referring to the Cartesian coordinate system **67** in FIG. **1**, lens **13** could control focusing in an Y-plane angle of light beam **19**, while lens **15** controls the Z-plane angle. Thus, the coaxial direction is the X-direction.

Referring now to FIGS. **3, 7**, and **8**, the leads **51, 53** of a voltage source **55** are connected to electrodes **45** in an alternating pattern. A focal length controller **57** is provided for controlling the voltage of voltage source **55**. Although both electrodes **45** on each film **35** have the same the same orientation, the adjacent films **35** (both above and below) have the opposite orientation so that the liquid crystal **47** lying therebetween is exposed to the voltage potential. Thus, the liquid crystal **47** in each cell or space between the films **35** may be manipulated simultaneously and in unison. The amount of voltage required to manipulate liquid crystals **47** is minimized as the spacing between films **35** is only 50 microns.

Note that electrodes **45** do not extend across the entire width of films **35** and substrates **41, 43**. In the embodiment shown, electrodes **45** only cover about two-thirds of the surface area of their respective substrates. Thus, a portion of the birefringent liquid crystal **47** lying between adjacent films **35** (above and below the left sides of films **35**) is not subjected to the voltage potential in order to vary the focal length of lens assembly **11**. Since, the minimum focal length is 10 mm and the difference between the ordinary (left side) and extraordinary (right side) refractive indexes of liquid crystal **47** is about 0.2, the radius of electrodes **45** must be no larger than the product of the focal length and the index difference (hence, 10 mm×0.2=2 mm radius).

In FIG. **7**, the applied voltage is zero, so liquid crystals **47** are identically aligned and oriented on both sides of films **35** (only two films shown). In FIG. **8**, the applied voltage does not equal zero, so the alignment direction of the liquid crystals **47** on the right side of films **35** are proportionately reoriented, and the liquid crystals **47** on the left side of films **35** remain unaffected. This changes the refractive index of the liquid crystals **47** and, thus, the focal length of lens assembly **11**.

Note that since lenses **13, 15** are spaced apart from each other along the X-axis, the voltages applied to them must be different in order to focus at the same X-axial point **21**. The focal length of lens **15** should be longer than that of lens **13**. Since the difference in the focal lengths is fixed by the configuration, the relation of the applied voltage to lenses **13, 15** can be calculated. Controller **57** calculates the applied voltages to lenses **13, 15** according to the information from the bar code reader. For example, if the focal length of lens **15** is 15.0 mm, and the total thickness of spacer plate **17** and lens **13** is 5.0 mm, the focal length of lens **13** would be 10 mm. Lenses **13, 15** focus light **19** simultaneously to a single point **21**.

In operation (FIGS. **9–13**), library **12** has a base **61** containing a plurality of drives (not shown) and a door **63** with an opening **64**. Door **63** is pivotally mounted to base **61** and is normally closed, but shown open in FIG. **9**. A mail slot or cartridge input/output (I/O) station **65** is mounted to door **63** (shown exploded from door **63** in FIG. **9**). Station **65** has a generally cylindrical, stationary body or magazine **71** with a coaxial door **73** that is pivotable or rotatable about the Z-axis relative to body **71**. Door **73** has a generally cylindrical shape and is shown open in FIG. **10** and closed in FIG. **11**. Magazine **71** has a plurality of parallel, cartridge storage slots **75**, each of which may contain one or more data cartridges **77** (two shown). Cartridges **77** may comprise tape, magneto-optical disk, digital versatile disk (DVD), high density floppy disks, or high density removable hard disk cartridges. Typically, library **12** does not have mixed media in it, but it is capable of handling such. Cartridges **77** are exported from library **12** in the +X direction, and imported in the −X direction. A robotic picker **79** (FIG. **9**) moves cartridges **77** to and from magazine **71** in the Y-Z plane.

When door **73** is open (FIG. **10**), a user can manually insert cartridges **77** into or remove them from slots **75** in magazine **71** through opening **64** in door **63**. When door **73** is closed by the user, robotic picker **79** can access the cartridges **77** placed into slots **75** (cartridge import). Alternately, when door **73** is closed, picker **79** can place more cartridges **77** into magazine **71** for removal from library **12** (cartridge export). Both of these operations are necessary since library **12** has a finite amount of cartridge storage space. Inactive cartridges which still contain valuable data are exported and shipped to a warehouse, the lowest tier in the data storage hierarchy. Each inactive is cartridge is replaced by a newly imported cartridge.

Referring now to FIGS. **11** and **12**, a plurality of sensors **11** are mounted to an inner portion **81** of door **73** and, thus, rotatable therewith. Sensors **11** are vertically arrayed to align with the slots **75** of magazine **71** in a one-to-one ratio. Door **73** and sensors **11** pivot relative to stationary magazine **71**. Power to and electrical signals from sensors **11** are transmitted on cable **83**. Cable **83** also carries power to a motor **85** that opens and closes door **73**. A master cable (not shown) extends from motor **85** and sensors **11** to controller **57**. Door **73** allows a user to manually access cartridges **77** in library **12** through opening **64**.

A bar coded label **87** is affixed to a rear side edge of each cartridge **77**. Labels **87** may also be located adjacent to cartridges **77** near slots **75** (not shown). The lines of the bar code are parallel to the axis of rotation of sensors **11**. The orientation of the bar code lines causes the sensors **11** to sweep along a line perpendicular thereto. In the preferred embodiment, door **73** is pivoted and sensors **11** pivot past the rear side edges of stationary cartridges **77** to scan labels **87**. It is the swinging of door **73** which moves sensors **11**, with their liquid crystal lenses **13, 15**, across the labels **87** which identifies cartridges **77** in station **65** to controller **57**. If the bar code reader cannot read the code on a label **87**, controller **57** changes the focal length of lenses **13, 15** in the respective sensor **11** to focus the code image on the reader.

Alternatively, sensors **11** remain stationary and magazine **71** is pivoted about the Z-axis (FIG. **13**) by motor **85**. Sensors **11** read the barcodes **87** (not shown) on the backs of cartridges **77** as magazine **71** sweeps around. This alternate embodiment also utilizes a siding planar door **89** rather than the cylindrical door **73** of the preferred embodiment. Door **89** may be configured to move or slide in either the Y-direction or in the Z-direction to allow a user to manually access cartridges **77** through opening **64** in library **12**. With both of these embodiments, there is no mechanical motion of the components of sensor **11**. Thus, the focus action is always fast and responsive.

The information scanned from the cartridges **77** in magazine **71** is relayed to controller **57** or a central data base for processing. The robotic picker **79** would then move or handle individual cartridges **77** based on instructions from controller **57**. However, controller **57** must identify each cartridge **77** before giving commands to picker **79**. Thus, controller **57** can give instructions to picker **79** as to which cartridges **77** are to be stored in which slots **75** and which cartridges (if any) are to be directed into drives for immediate data I/O operations.

The invention has several advantages. The lens assembly uses liquid crystal lenses that can change their focal lengths at high speeds by merely varying an applied voltage in response to the focal length controller. The lens assembly is completely stationary and utilizes no moving parts. This design is readily incorporated into automated storage libraries having various configurations. The invention is well suited for libraries which contain various types of storage media or bar code labels or differing sizes.

While the invention has been shown or described in only some of its forms, it should be apparent to those skilled in the art that it is not so limited, but is susceptible to various changes without departing from the scope of the invention.

We claim:

1. A variable focal length lens, comprising:

a polarized liquid crystal lens body;

a plurality of parallel substrates containing liquid crystal therebetween mounted to the lens body;

an electrode mounted to each of the substrates, wherein adjacent ones of the electrodes apply a variable voltage to the liquid crystal located therebetween for altering a refractive index of the liquid crystal and, thus, adjusting a focal length of the lens; and wherein

the electrodes only cover a portion of their respective substrates such that the liquid crystal between said adjacent ones of the electrodes is birefringent.

2. The variable focal length lens of claim **1** wherein each of the substrates is coated with an alignment material.

3. The variable focal length lens of claim **2** wherein the alignment material sets a desired alignment direction for the liquid crystal.

4. The variable focal length lens of claim **1** wherein adjacent ones of the substrates are spaced apart by a distance in the range of 30 to 70 microns, and wherein each of the substrates has a thickness of approximately 2 microns and a width of approximately 70 microns.

5. The variable focal length lens of claim **1** wherein the focal length of the lens has a range of approximately 10 mm to infinity.

6. The variable focal length lens of claim **1** wherein the only moving part of the lens is the liquid crystal.

7. The variable focal length lens of claim **1** wherein the electrodes on the substrates are generally arcuate in shape.

8. A variable focal length lens assembly, comprising:

a pair of polarized liquid crystal lenses;

a plurality of parallel substrates containing liquid crystal therebetween mounted to each of the lenses;

a single electrode associated with each of the substrates, wherein adjacent ones of the electrodes apply a variable voltage to the liquid crystal located therebetween for altering a refractive index of the liquid crystal and, thus, adjusting a focal length of the lens assembly; and wherein

said adjacent ones of the electrodes only refract a portion of the liquid crystal located therebetween such that another portion of said liquid crystal located therebetween is not subjected to the variable voltage in order to vary the focal length of the lenses.

9. The variable focal length lens assembly of claim **8** wherein each of the substrates is coated with an alignment material for setting a desired alignment direction for the liquid crystal.

10. The variable focal length lens assembly of claim **8** wherein adjacent ones of the substrates are equally spaced apart by a distance in the range of 30 to 70 microns, and wherein each of the substrates has a thickness of approximately 2 microns and a width of approximately 70 microns.

11. The variable focal length lens assembly of claim **8** wherein the focal length of the lens assembly has a range of approximately 10 mm to infinity.

12. The variable focal length lens assembly of claim **8** wherein the only moving part of the lens assembly is the liquid crystal.

13. The variable focal length lens assembly of claim **8** wherein the electrodes on the substrates are generally arcuate in shape.

14. The variable focal length lens assembly of claim **8** wherein the lenses are separated by a transparent spacer having a width that is adapted to equal one-half wavelength of a light source used in conjunction with the lens assembly.

15. A variable focal length lens assembly, comprising:

a pair of polarized liquid crystal lenses;

a transparent spacer located between the lenses;

a plurality of parallel substrates containing liquid crystal therebetween mounted to each of the lenses;

an alignment coating on each of the substrates for setting a desired alignment direction for the liquid crystal; and

a single electrode located between each of the substrates and their respective alignment coatings, wherein adjacent ones of the electrodes apply a variable voltage to a portion of the liquid crystal located therebetween for altering a refractive index of said portion of the liquid crystal such that another portion of said liquid crystal located therebetween is not subjected to the variable voltage, thereby adjusting a focal length of the lens assembly.

16. The variable focal length lens assembly of claim **15** wherein adjacent ones of the substrates are equally spaced apart by a distance in the range of 30 to 70 microns, and wherein each of the substrates has a thickness of approximately 2 microns and a width of approximately 70 microns.

17. The variable focal length lens assembly of claim **15** wherein the focal length of the lens assembly has a range of approximately 10 mm to infinity.

18. The variable focal length lens assembly of claim **15** wherein the only moving part of the lens assembly is the liquid crystal.

19. The variable focal length lens assembly of claim **15** wherein the electrodes on the substrates are generally arcuate in shape.

20. The variable focal length lens assembly of claim **15** wherein the spacer has a width that is adapted to equal one-half wavelength of a light source used in conjunction with the lens assembly.

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